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Validation of Prototype Continuous Real-Time Vital Signs Video Analytics Monitoring System “CCATT Viewer”



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for September 2014 to November 2017**



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14. ABSTRACT We have developed an automated physiological data-organizing and information-summary system (Critical Care Air Transport Team (CCATT) viewer) to present aggregated information from multiple data sources, provide at-a-glance summaries of clinical data, and assist with prioritizing care for multiple patients in intensive care units (ICU). In the Maryland Shock Trauma Center, the viewer displays 230 beds (grouped into 14 clinical units) for up to 72 hours of continuous vital signs data with 1-minute temporal resolution. It visualizes vital signs that are routinely monitored for patients with shock, burns, trauma, traumatic brain injury, or respiratory failure. We conducted the prospective survey in our trauma center ICU. Over 60% of clinicians believe the viewer enhanced their understanding of their patients' condition. The survey results indicate that when attending physicians look at the CCATT viewer for 1 minute or less, 10% of the time they change their clinical plan. Due to the success of this system, our medical center neuro ICU also adopted this viewer for daily patient care planning and rounding.					
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1.0 EXECUTIVE SUMMARY

Military Critical Care Air Transport Teams (CCATTs) have demonstrated reliable capability to evacuate critically injured patients from deployed hospitals. However, the long-range aeromedical transportation of patients has many challenges regarding in-flight assessments that are required to rapidly render appropriate clinical support. Clinical decision-making is further confounded by an aeromedical environment characterized by confined space, noise, vibration, and limited visibility. An automated physiological data-organizing and information-summary system could present aggregated information from multiple data sources, provide at-a-glance summaries of clinical data, and assist with prioritizing care for multiple patients. A prototype CCATT vital signs (VS) viewer has been specifically designed and implemented for this unique and hostile environment. The viewer's capacity for data throughput and stability in a major level 1 trauma center was also tested. It was evaluated for its usefulness in a critical care air transport setting.

In the University of Maryland Shock Trauma Center, the viewer displays 230 beds (grouped into 14 clinical units) for up to 72 hours of continuous VS data with 1-minute temporal resolution. It shows up to nine VS in complete trajectories (shock index, heart rate, systolic blood pressure, oxygen saturation, intracranial pressure, etc.) that are routinely monitored for patients with shock, burns, trauma, traumatic brain injury, or respiratory failure. The system has high reliability; with asynchronous communication, it can tolerate temporary network failure.

To evaluate the viewer's usefulness, we conducted surveys during our trauma center neurotrauma and multi-trauma intensive care unit (ICU) morning rounds from February 15, 2017, to June 30, 2017. In total, 908 surveys were collected. The questionnaire collected changes to physicians' opinions before and after seeing the patient's data on the viewer in each ICU round. The physicians were asked questions regarding the patient's stability, status, and need for a higher or lower level of care. Physicians were also asked if they intentionally plan to change interventions after seeing the viewer. Last, they were asked to give an overall rating on how the viewer helped them understand the patient's physiologic condition in that round.

The results indicate attending physicians, after looking at the CCATT viewer for 1 minute or less and having the viewer's more detailed and summarized information, as often as 10.1% of the time changed their clinical plan. In an overall rating of the CCATT viewer, physicians were asked if the viewer enhanced their understanding of the patient's condition—55.0% strongly agree, 56.6% agree, 35.4% neutral, 2.8% disagree, and 0.2% strongly disagree.

In a noisy, busy, and confined transport aircraft, loosely organized physiological data, oversaturated information delivery, and limited visual assessment may reduce the capability of a small clinical team to recognize changes in physiologic status and prioritize care. The CCATT viewer prototype demonstrates a method to assemble large quantities of data from multiple sources and represent trends in each patient's condition with simple color codes, greatly improving situational awareness. Our prospective CCATT viewer evaluation study conducted in the trauma center neuro and multi-trauma ICU demonstrated the effectiveness of the viewer.

2.0 INTRODUCTION

2.1 Background

The vast amounts of high-quality, continuous, electronic data garnered by modern physiologic monitoring systems have the potential to provide an unprecedented view of dynamic physiologic response to injury, illness, and intervention. Once casualties enter continuous care, from battlefield on, a vast quantity of data is collected. It is practically important to organize those data and present meaningful analysis for efficient decision-support. Many years ago, a novel prototype video display system was implemented from the University of Maryland Vital Signs Data Recording (VSDR) project that has been deployed on a translational basis in the neurotrauma critical care unit, the two multi-trauma critical care units, the trauma resuscitation unit (TRU), and operating rooms (OR) in the Shock Trauma Center (STC) [1-4]. This display allows clinicians to track and monitor vital signs (VS) trends in up to 66 patient locations with a display of the patients' physiological status over the previous 24 hours in a single real-time monitor, with critical physiologic changes coded as green, yellow, and red based on threshold values gleaned historically from episodic, manually collected and processed data. With the advances in computing and visualization techniques, we seek to develop and optimize this VS viewer so that it can be used for a general purpose in monitoring a group of patients.

This work has two outcomes of direct and important clinical applicability. First, the VS viewer can provide clinicians with the capability to monitor individual patient trends that may improve overall decision-making. Since mechanically ventilated trauma patients may require multiple interventions to maintain cerebral perfusion and oxygenation, reduce intracranial pressure (ICP), and optimize brain trauma index (BTI) and shock index (SI) to ensure ideal long-term outcome, a significantly improved display of VS patterns will improve patient assessment and clinical decision-making. Second, the monitoring system allows remote monitoring of groups of patients through a display that is optimized to assist ongoing triage decisions and provide clinicians the ability to quickly identify patients in need of rapid intervention. Since Critical Care Air Transport Teams (CCATTs) and aeromedical evacuation (AE) staff cannot view all patient locations simultaneously using traditional monitors, this capability will facilitate management of a group of patients. Innovative visual analytics of the complex array of real-time physiological data will provide an at-a-glance view of multiple patients to promote instant decisions on attention allocation.

As a foundation for future studies, the demonstration of a novel method for analyzing digital monitoring data has the potential to provide a basis for an adaptive model capable of displaying prognostic information to predict long-term outcomes which, based on an individual's actual physiologic thresholds rather than an estimate based on past group experience, will individualize decision-support for patients on an unprecedented level.

2.2 Military Relevance

The U.S. Air Force (USAF) CCATT is a highly specialized medical asset team that can operate a portable intensive care unit (ICU) onboard any transport aircraft during flight and has been credited with allowing trauma surgeons to perform far forward damage control surgery, knowing that these patients could be quickly transported rearward with full support. This rapid transport of complex patients with multi-system trauma, shock, burns, and respiratory failure

who are in hemodynamic flux requires continual resuscitation, stabilization, advanced care, and life-saving interventions during air transport; however, currently available advanced ICU monitoring systems suitable for the needs of such patients were developed for use in stable, hospital-based settings, not in the crowded, noisy, vibrating, and sometimes frankly jolting environment of air evacuation or long-distance air transport.

The critical care air transport environment may require patients to be completely covered with warming blankets and placed in a litter stanchion, which limits access to the patient, further complicating patient assessments. Each CCATT may be responsible for up to six critical patients. Traditional monitor alarms are not audible on the aircraft due to aircraft noise. During takeoff and landing, observation of the patients may be even more challenging. Additionally, numerous less severely injured patients are evacuated through the AE system without any type of continuous monitoring. Because of these identified challenges, remote monitoring of groups of patients, including monitoring of VS trends and current vital information, has been identified by USAF CCATT and AE as a high priority gap.

2.3 Previous Work

From 2008-2012, a prototype VS viewer was conceptualized, designed, and deployed in the University of Maryland advanced trauma ICU system. It is capable of recording, analyzing, and simultaneously visually displaying a range of clinical monitoring information, including real-time analysis and display of indices linked algorithmically to outcome [5-7]. Much of this work was done with internal and USAF funding and working closely with USAF clinicians.

The prototype system that had been deployed throughout the trauma ICUs, TRU, and ORs displays conventional real-time physiologic information, including ICP, cerebral perfusion pressure (CPP), and mean arterial pressure data as well as ongoing, real-time calculation of shock index ($SI = \text{heart rate [HR]} / \text{systolic blood pressure [SBP]}$) and BTI ($= CPP / ICP$) in an easily appreciable visual display. In the previous display version, data and indices were linked to outcome data and expert treatment guidelines, so the color-based visual alarm system provided continuously updated access to the patient's current physiologic risk status and recent trends as a basis for clinical decision-making.

As shown in Figure 1, visual analytics of the complex array of real-time physiological data provide an at-a-glance view of multiple patients as well as a view of each patient's condition over the past 1 to 24 hours. This has the potential to support essentially instant identification of an individual patient who is in need of immediate attention among a large group of fragile patients being transported in a difficult environment. Also, this capacity can be deployed at the bedside or to a remote monitor to maximize situational awareness.

The prototype VS viewer had shown great potential in organizing massive amounts of physiologic data and efficiently displaying concise information for clinical decision-making in a busy ICU environment. However, the previous version was built on a system that requires large amounts of computing power. Moreover, its images were static, which provided limited function for data exploring. The system's stability and scalability also needed improvement.

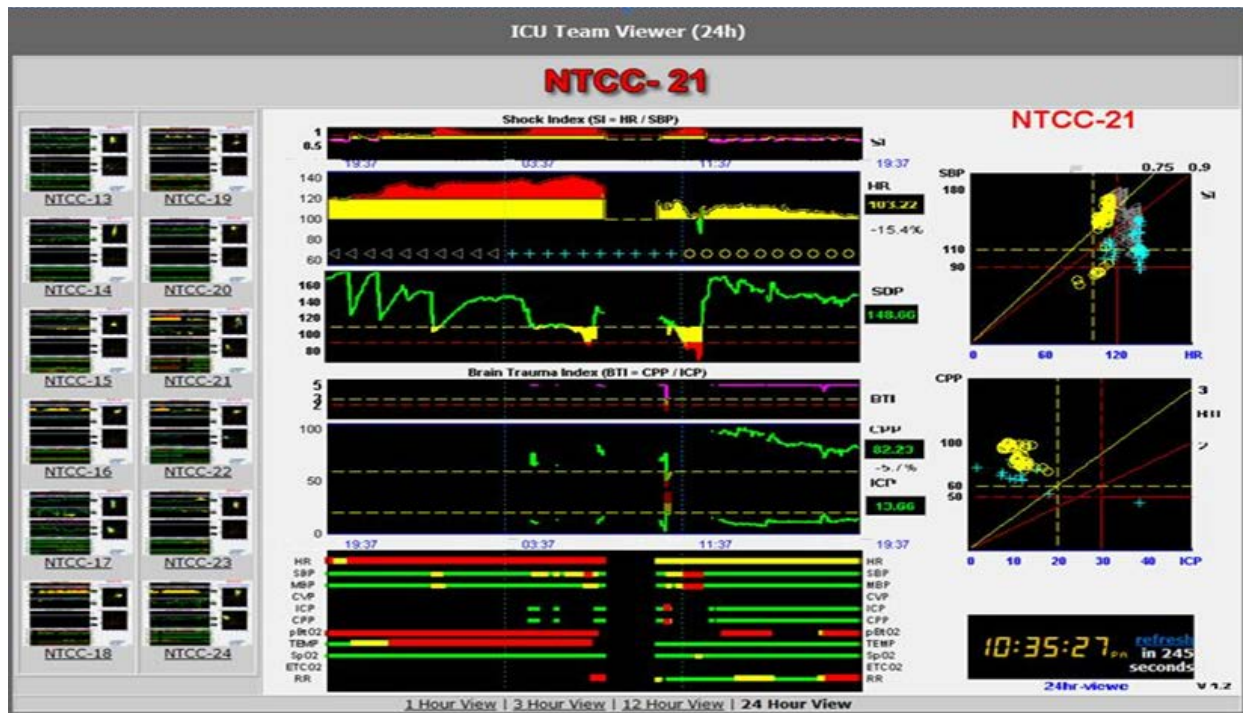


Figure 1. Interface of previous prototype real-time bedside VS viewer.

3.0 SYSTEM DESIGN

The new system design aimed for a lightweight, balanced server-client, portable architecture. The system is used to organize and visualize multiple patients' full trajectories of physiologic data. It is expected to provide high visibility with reasonable stability and scalability, even in busy, crowded, and unstable environments.

3.1 System Architecture

The CCATT viewer 2.0 is built on new system architecture that supports real-time asynchronous web applications with triple redundancy for web service fault tolerance. Figure 2 illustrates the system architecture. Based on the triple-redundant data servers (blue dots), VS data of each 1-minute median are submitted to three independent databases distributed on the three CCATT servers (red dots). As dual-purpose servers, the CCATT servers also respond to requests from clients in the University of Maryland Medical Center intranet to generate displaying content and to update it regularly.

An auto server switch has been implemented to improve user experience on the system reliability. Each active client regularly checks if the current CCATT server is available. In case the current server fails, the client will be seamlessly redirected to the next available CCATT server.

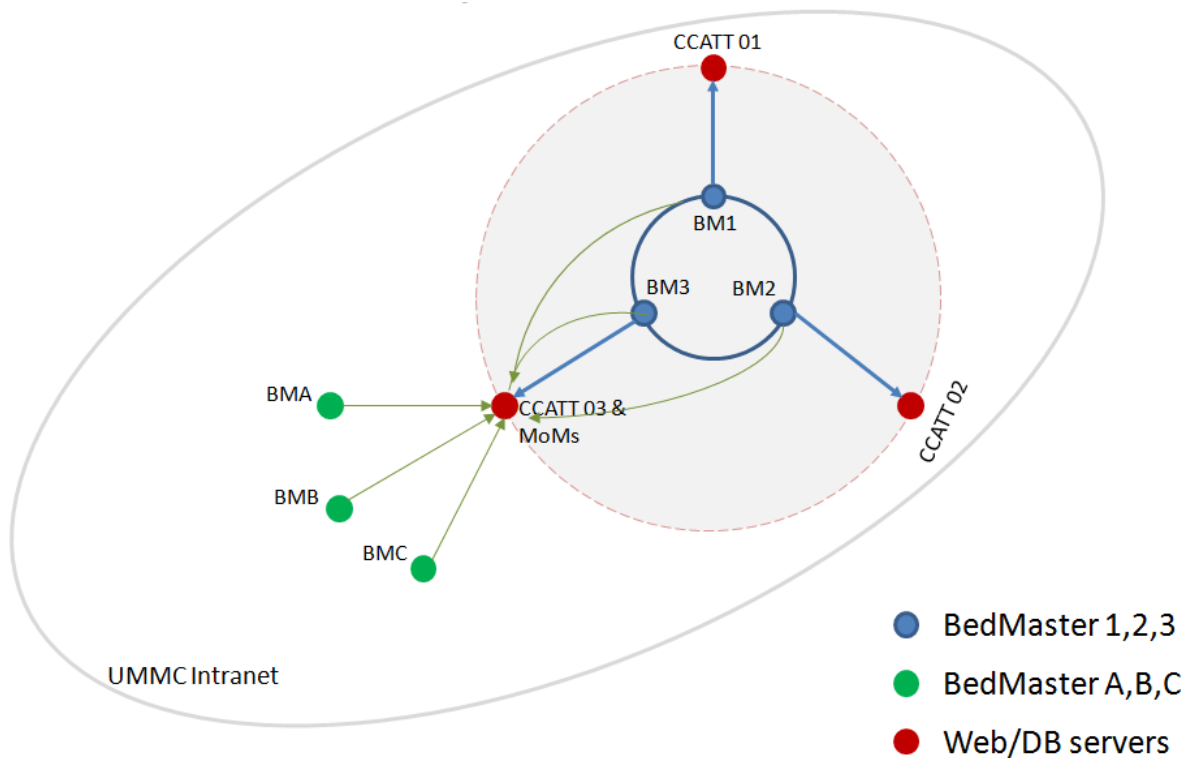


Figure 2. Illustration of a triple-redundant configured CCATT system communication architecture. *BM = BedMaster; MoMs = monitor of monitors; UMMC = University of Maryland Medical Center.*

The triple-redundant or double-redundant system could be useful in managing hundreds of bedside monitor data sources. With too many data sources, a single central server may suffer from a high chance of failure. However, multiple collaborating servers could reduce data collection failure. On the other hand, in a compact ICU environment (e.g., CCATT) with a few to a dozen patients, a single server or double-redundant system would be sufficient to maintain a high data collection rate.

3.2 Viewer Elements Design

For detailed elements to display, as well as their color, line styles, and locations on the screen, we surveyed 47 clinicians (24 medical doctors, 18 registered nurses, and 5 respiratory therapists). Among them, 20 were military personnel and 27 civilians. Institutional wise, there were 36 participants from the University of Maryland, Baltimore, and 11 from the University of Cincinnati. After the feedback survey was completed, a team of clinicians met to review the feedback survey results to reach a consensus opinion of the viewer's visual appearance. One of the most important consensus opinions was the threshold set for VS. For a given VS, it will be displayed as a temporal trajectory with certain colors, depending on the threshold range that its value falls into. Table 1 summarizes the optional threshold distributions for some important VS. Based on these threshold values, a consensus set of CCATT color coding cut-offs was determined (Table 2). These values are set as fixed parameters under the consideration of simplified and consistent user interface. Technically, the threshold settings can be modified or customized in the configuration file.

Table 1. Surveyed Thresholds for Heart Rate, Systolic and Diastolic Blood Pressure, Blood Oxygen Saturation, and Temperature

VS	High – Red High Lower Limit	Yellow High		Green		Yellow Low		Low – Red
		Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Low Upper Limit
HR								
Mean	121	119	100	100	62	59	50	49
Median	120	119	101	100	60	59	51	50
Mode	120	119	101	100	60	59	51	50
SD ^a	8.68	8.59	4.26	4.90	5.98	5.09	4.83	4.57
N	19	17	17	17	17	17	17	19
SBP								
Mean	175	174	147	145	103	102	88	86
Median	180	179	150	149	101	100	90	89
Mode	180	179	160	159	100	99	81	80
SD	14.99	15.43	13.08	13.07	8.60	8.55	6.59	5.71
N	17	16	16	15	15	16	17	18
DBP ^a								
Mean	103	102	86	85	56	56	43	43
Median	100	103.5	88	87	60	59	41	40
Mode	100	99	91	90	60	59	41	40
SD	12.40	13.41	14.28	14.28	9.05	9.62	7.54	7.55
N	14	12	12	12	12	13	13	14
SaO2 ^a								
Mean				100	93.92857143	92.9	89.3	88.3
Median				100	94.5	93.5	90	89
Mode				100	95	94	90	89
SD				0.00	1.77	1.77	2.37	2.37
N				14	14	14	14	14
Temp								
Mean	39	39	38	38	36	36	35	35
Median	39	39	38	38	36	36	35	35
Mode	39	39	38	38	36	36	35	35
SD	1.11	1.08	0.47	0.46	0.64	0.48	0.70	0.66
N	17	13	13	13	13	12	12	16

^aDBP = diastolic blood pressure; SaO2 = blood oxygen saturation; SD = standard deviation.

Table 2. CCATT Viewer Color Coding Cut-Off Values

VR	Red	Yellow	Green
HR	<50 or >120	50-59 or 100-119	59-100
SBP	<81 or >180	81-99 or 160-179	100-160
DBP	<41 or >100	41-59 or 91-99	60-90
MBP ^a	<51 or >90	51-59 or 71-89	60-70
NSBP ^a	<81 or >180	81-99 or 160-179	100-159
NDBP ^a	<41 or >100	41-59 or 91-99	60-90
NMBP ^a	<51 or >90	51-59 or 71-89	60-70
SpO2 ^a	<90	90-95	95-100
“PULSE RATE”	<90	90-94	94-100
TEMP	<35 or >39	35-36 or 38-39	36-38
RR ^a	<8 or >30	8-9 or 26-30	10-25
ICP	>30	20-30	0-19
EtCO2 ^a	<20 or >50	20-30 or 40-50	30-40
SI	>1.2	>0.9	<0.9
CPP	<50	50-60	>60
BTI	<2	2-3	>4

^aEtCO2 = end-tidal carbon dioxide; MBP = mean blood pressure; NDBP = normal DBP; NMBP = normal MBP; NSBP = normal SBP; RR = respiratory rate; SpO2 = blood oxygen saturation (pulse oximetry).

3.3 Viewer Interface Design

The CCATT viewer provides a rich interactive interface for data monitoring, exploring, and recording. First, bed units are organized based on clinical divisions, such as TRU, OR/computed tomography, neurotrauma critical care, etc. Figure 3 demonstrates the group of bed units. On the left panel, a list of all groups can be used as a shortcut to bed units. Selecting a specific unit, a default 24-hour view is displayed for shock index (SI=HR/SBP), HR, SBP, ICP, CPP, BTI, EtCO2, etc. To better utilize the space, if ICP is not collected, the space is used to plot the next available VS. An overview of all collected VS is summarized with colored horizontal bars at the bottom.

When a specific bed is selected, a page for bed unit view will be displayed. Figure 4 demonstrates the structure of the information grouped. Areas 1, 2, and 3 on the top are used for navigation, basic unit and time information, and user login. Area 4 on the left panel collects all beds in the same units and shows the thumbnails of their real-time VS. Such grouping of thumbnails maintains visibility of other beds while the user is focusing on a specific case. Area 5 is the main place for displaying the selected bed's major VS. Area 6 is reserved for displaying some useful diagnostic tools. Area 7 at the bottom is for other auxiliary functions.

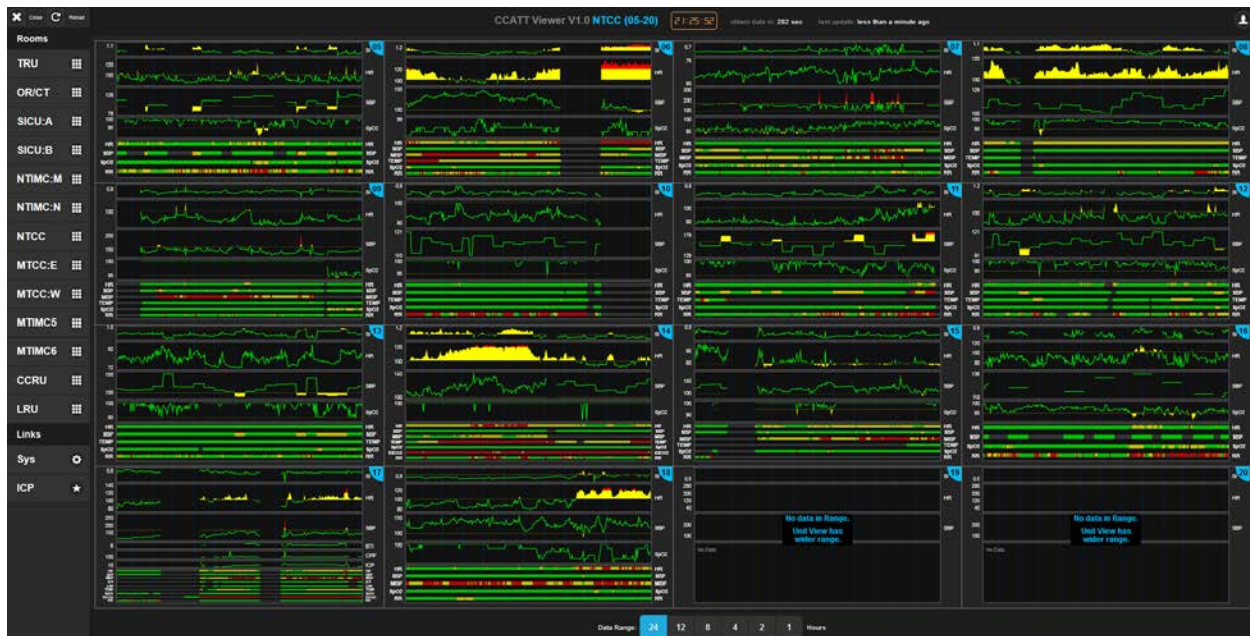


Figure 3. A group view of the CCATT viewer, with the default 24-hour data display.

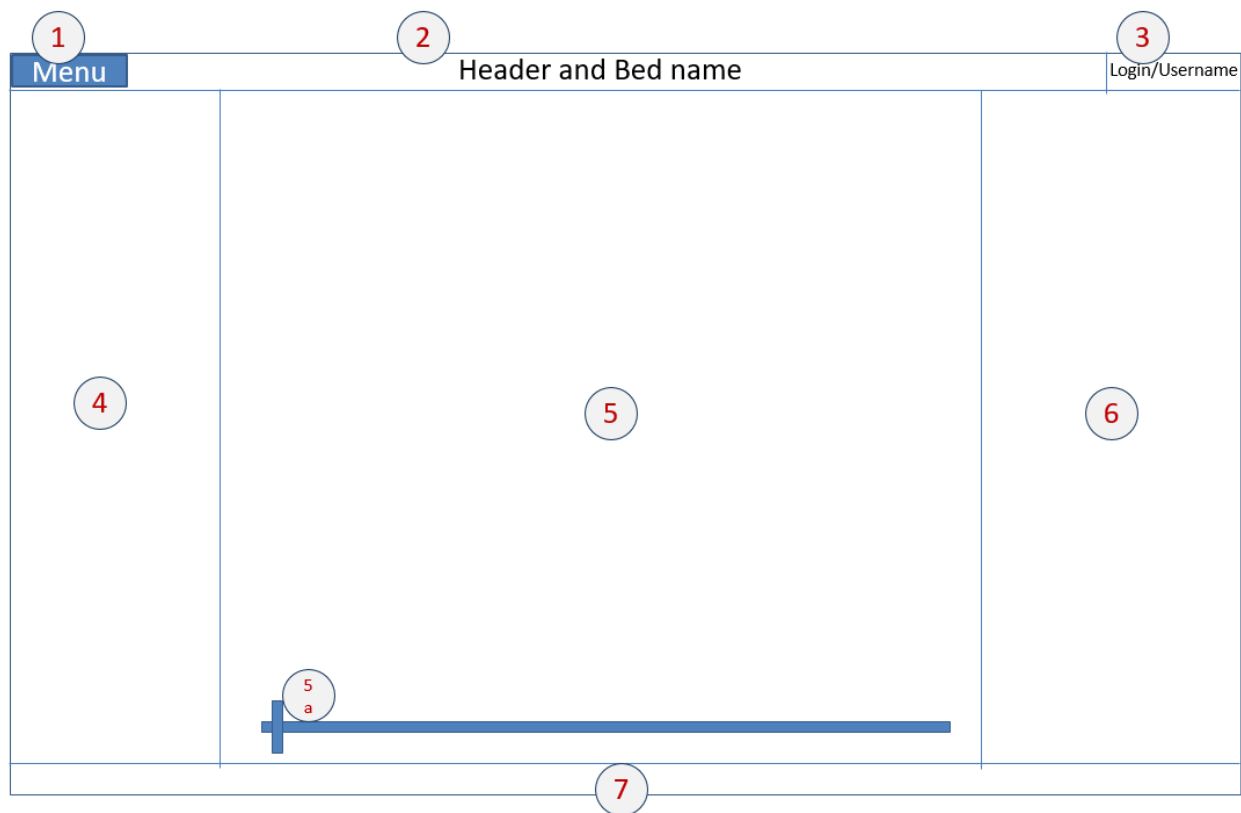


Figure 4. The structure of unit view of CCATT viewer and its main areas for grouped information.

The viewer can host some special diagnostic tools. For example, SI is a commonly used blood transfusion diagnosis tool. The CCATT adds a two-dimensional (2D) SI diagram to show the changing trajectory. To present the temporal information, a spectrum of colors ranging from blue (cold) to red (warm) is used to code the past (blue) and current (red) time. The top right plot in Figure 5 shows an example of unit view. Figure 6 shows an SI plot in a closeup look. Similarly, the BTI (= ICP/CPP) can also be visualized in the 2D plot.



Figure 5. A unit view of CCATT viewer, with a default 24-hour data display.

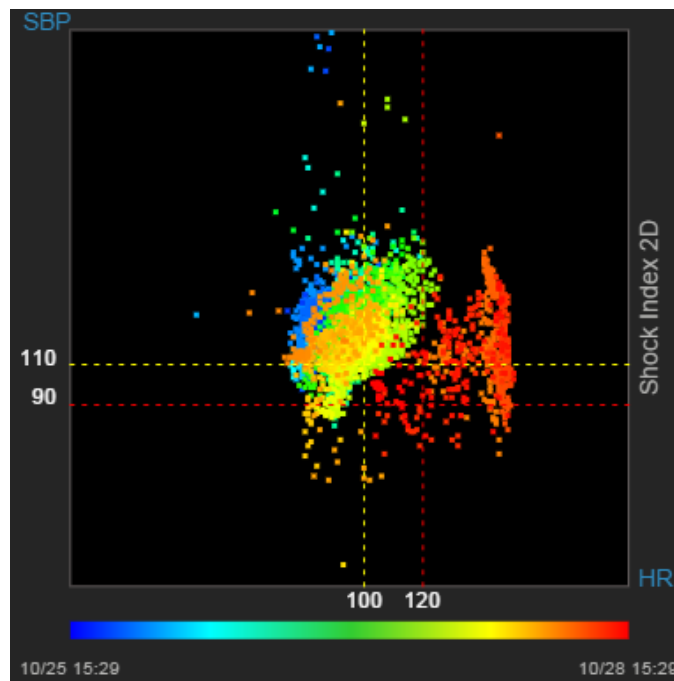


Figure 6. An example 2D SI plot. The colored scatter plot shows from past (blue) to recent (red), from which we can observe a deteriorated SI in a 3-day range.

Mouse and touch screen interactive operations are also implemented. In a desktop or tablet environment, moving the cursor will draw a vertical line to show current time and the real VS values at the selected time. By selecting a time interval, the reviewer will zoom in to the selected time interval for local details. A preset time intervals setting is placed at the bottom for 1, 2, 4, 8, 12, 24, 48, and 72 hours view. In the 2D SI and BTI plots, moving the cursor along the color spectrum, the corresponding time and HR/SBP points are highlighted.

In VS value plots, green/yellow/red color code is used to show normal, warning, and alert regions. With a set of pre-defined thresholds (Table 2), VS above/below warning or alert thresholds are filled with yellow and red blocks. Such filled color can draw attention from the users to quickly identify cases of special interest.

The CCATT viewer provides a handy button to allow users to save an instant screenshot. This is useful for clinicians to use the system as a recording tool during routine rounding or diagnosis.

3.4 Viewer Computing Performance

The CCATT viewer runs efficiently on regular mainstream personal computers (PCs). The current CCATT server has an Intel i5 1.9-GHz central processing unit, 16 GB memory, and Windows 7. The CCATT server consumes a small amount of system resources. A mini-computing device (e.g., Raspberry Pi model B) can be used as a server. A typical data request from a client (24 hours view) could transfer 16 (units) x 1440 (minutes) x 16 (VS) = 0.37 million data points. Such an amount of data can be rendered in real-time on the left panel thumbnails view and the main unit view. As a debug tool shows (Figure 7), the drawing time is at the hundreds millisecond level. With Ajax (asynchronous Javascript and XML) techniques, CCATT displaying is updated every 1 minute without refreshing the entire page. Data are compressed at a level of balanced size and parsing efficiency.

Heavy (Bottom Up) ▼ 🔍 ✕ ↺		
Self Time	Total Time	Function
5153.1 ms	5153.1 ms	(idle)
183.9 ms 21.51 %	183.9 ms 21.51 %	(program)
157.3 ms 18.40 %	459.4 ms 53.74 %	▶ drawUnitData (index):271
87.2 ms 10.20 %	117.2 ms 13.71 %	▼ drawDataOverView (index):742
87.1 ms 10.18 %	117.2 ms 13.71 %	▶ drawUnitData (index):271
0.1 ms 0.01 %	0.1 ms 0.01 %	▶ drawDataOverView (index):742
66.8 ms 7.81 %	66.8 ms 7.81 %	(garbage collector)
63.2 ms 7.39 %	134.0 ms 15.67 %	▶ drawOneData (index):1042
22.6 ms 2.65 %	25.5 ms 2.98 %	▶ parseDateTime (index):226
20.3 ms 2.37 %	192.0 ms 22.46 %	▶ success (index):1566
18.7 ms 2.19 %	18.7 ms 2.19 %	▶ fillText
16.6 ms 1.95 %	175.8 ms 20.56 %	▶ success (index):1492
16.4 ms 1.92 %	16.4 ms 1.92 %	▶ stroke
16.4 ms 1.92 %	16.4 ms 1.92 %	▶ measureText
15.4 ms 1.80 %	158.5 ms 18.54 %	▶ drawSideGroupData (index):1437
15.2 ms 1.78 %	158.9 ms 18.59 %	▶ drawGroupData (index):1452
14.6 ms 1.71 %	14.6 ms 1.71 %	▶ fill

Figure 7. A snippet of CCATT profile. For the non-idle time, the rendering function costs time at the hundreds millisecond level.

Within the triple-redundant architecture, data for update can be requested from any one of the three time-synchronized data servers. When one CCATT server fails, the client could detect the next available server and fetch the data. Users do not need to intervene in this switching process. The above features are further enhanced with a mobile app when CCATT viewer is used on tablets or smart phones. We built an app to stream and visualize data for hand-held devices. The app maximizes the use of limited screen space by automatically setting full screen view. It also remembers the server URL and increases the efficiency.

3.5 Auxiliary Function and System Pressure Test

To monitor system activity and quickly identify system failure, an enhanced “monitor of monitors” (MoMs) was designed based on the new system architecture. All data servers, including three VS trend data collectors (blue dots in Figure 2) and three waveform collectors (green dots in Figure 1), send the latest data with timestamps to the MoMs system. Figure 8 shows a snippet of the MoMs system. Each data server is represented by a large block (Figure 8). Each bed unit collected by such server is represented by a colored small box. If a bed unit is online in the last 5 minutes, the box is green, with the admission status (admitted or discharged) and the last HR value. If a bed unit is offline for longer than 5 minutes, the box is yellow. It turns red if the bed unit is offline longer than 6 hours. For VS of special interest, MoMs can use special colors to highlight. For example, ICP is an important VS for traumatic brain injured patients and is not often collected due to its intrusive nature. The MoMs system shows ICP collected unit in pink and its latest value.

TRU01 (A)-1	TRU02 (A) 80	TRU03 (A) 91	TRU04 (D)-1	TRU05 (D)-1	TRU06 (D)-1	TRU07 (A)-1	TRU08 (D)-1	TRU09 (A) 83	TRU10 (A) 86	TRU11 (A)-1
TRU12 (A) 88	TRU13 (A)-1	TOR1 (A)-1	TOR2 (A)-1	TOR3 (A)-1	TOR4 (A)-1	TOR5 (A)-1	TOR6 (A)-1	TOR7 (A)-1	TOR8 (A) 78	TOR9 (A)-1
TRUC11 (A) 102	TRUC12 (A)-1	MTIM05 (A) 102	MTIM06 (A) 108	MTIM07 (A)-1	MTIM08 (A) 98	MTIM01 (A)-1	MTIM02 (A) 81	MTIM03 (A) 106	MTIM04 (A) 108	MTIM21 (A) 99
MTIM22 (A)-1	MTIM23 (A) 100	MTIM24 (A) 73	MTIM25 (A) 51	MTIM26 (A) 108	MTIM27 (A) 90	MTIM28 (D)-1	MTIM29 (A) 109	MTIM30 (A) 87	MTIM31 (A) 88	MTIM32 (A) 96
MTIM33 (A) 104	MTIM34 (A)-1	MTIM35 (A) 127	MTIM36 (A) 127	CCR09 (D)-1	CCR10 (D)-1	CCR11 (A) 133	CCR12 (D)-1	CCR13 (A) 133	CCR14 (A)-1	CCR15 (A) 133
CCR16 (D)-1	CCR17 (A) 118	CCR18 (A) 118	CCR19 (A) 118	CCR20 (A) 118	CCR21 (A) 118	CCR22 (A) 118	CCR23 (A) 118	CCR24 (A) 118	CCR25 (A) 118	CCR26 (A) 118
MTCC11 (A) 121	MTCC12 (A) 121	MTCC13 (A) 121	MTCC14 (A) 121	MTCC15 (A) 121	MTCC16 (A) 121	MTCC17 (A) 121	MTCC18 (A) 121	MTCC19 (A) 121	MTCC20 (A) 121	MTCC21 (A) 121
MTCC22 (A) 121	MTCC23 (A) 121	MTCC24 (A) 121	MTCC25 (A) 121	MTCC26 (A) 121	MTCC27 (A) 121	MTCC28 (A) 121	MTCC29 (A) 121	MTCC30 (A) 121	MTCC31 (A) 121	MTCC32 (A) 121
NTCC01 (A) 121	NTCC02 (A) 121	NTCC03 (A) 121	NTCC04 (A) 121	NTCC05 (A) 121	NTCC06 (A) 121	NTCC07 (A) 121	NTCC08 (A) 121	NTCC09 (A) 121	NTCC10 (A) 121	NTCC11 (A) 121
NTCC12 (A) 121	NTCC13 (A) 121	NTCC14 (A) 121	NTCC15 (A) 121	NTCC16 (A) 121	NTCC17 (A) 121	NTCC18 (A) 121	NTCC19 (A) 121	NTCC20 (A) 121	NTCC21 (A) 121	NTCC22 (A) 121
NTCC23 (A) 121	NTCC24 (A) 121	NTCC25 (A) 121	NTCC26 (A) 121	NTCC27 (A) 121	NTCC28 (A) 121	NTCC29 (A) 121	NTCC30 (A) 121	NTCC31 (A) 121	NTCC32 (A) 121	NTCC33 (A) 121
NTCC34 (A) 121	NTCC35 (A) 121	NTCC36 (A) 121	NTCC37 (A) 121	NTCC38 (A) 121	NTCC39 (A) 121	NTCC40 (A) 121	NTCC41 (A) 121	NTCC42 (A) 121	NTCC43 (A) 121	NTCC44 (A) 121
NTCC45 (A) 121	NTCC46 (A) 121	NTCC47 (A) 121	NTCC48 (A) 121	NTCC49 (A) 121	NTCC50 (A) 121	NTCC51 (A) 121	NTCC52 (A) 121	NTCC53 (A) 121	NTCC54 (A) 121	NTCC55 (A) 121
NTCC56 (A) 121	NTCC57 (A) 121	NTCC58 (A) 121	NTCC59 (A) 121	NTCC60 (A) 121	NTCC61 (A) 121	NTCC62 (A) 121	NTCC63 (A) 121	NTCC64 (A) 121	NTCC65 (A) 121	NTCC66 (A) 121
NTCC67 (A) 121	NTCC68 (A) 121	NTCC69 (A) 121	NTCC70 (A) 121	NTCC71 (A) 121	NTCC72 (A) 121	NTCC73 (A) 121	NTCC74 (A) 121	NTCC75 (A) 121	NTCC76 (A) 121	NTCC77 (A) 121
NTCC78 (A) 121	NTCC79 (A) 121	NTCC80 (A) 121	NTCC81 (A) 121	NTCC82 (A) 121	NTCC83 (A) 121	NTCC84 (A) 121	NTCC85 (A) 121	NTCC86 (A) 121	NTCC87 (A) 121	NTCC88 (A) 121
NTCC89 (A) 121	NTCC90 (A) 121	NTCC91 (A) 121	NTCC92 (A) 121	NTCC93 (A) 121	NTCC94 (A) 121	NTCC95 (A) 121	NTCC96 (A) 121	NTCC97 (A) 121	NTCC98 (A) 121	NTCC99 (A) 121
NTCC100 (A) 121	NTCC101 (A) 121	NTCC102 (A) 121	NTCC103 (A) 121	NTCC104 (A) 121	NTCC105 (A) 121	NTCC106 (A) 121	NTCC107 (A) 121	NTCC108 (A) 121	NTCC109 (A) 121	NTCC110 (A) 121
NTCC111 (A) 121	NTCC112 (A) 121	NTCC113 (A) 121	NTCC114 (A) 121	NTCC115 (A) 121	NTCC116 (A) 121	NTCC117 (A) 121	NTCC118 (A) 121	NTCC119 (A) 121	NTCC120 (A) 121	NTCC121 (A) 121
NTCC122 (A) 121	NTCC123 (A) 121	NTCC124 (A) 121	NTCC125 (A) 121	NTCC126 (A) 121	NTCC127 (A) 121	NTCC128 (A) 121	NTCC129 (A) 121	NTCC130 (A) 121	NTCC131 (A) 121	NTCC132 (A) 121
NTCC133 (A) 121	NTCC134 (A) 121	NTCC135 (A) 121	NTCC136 (A) 121	NTCC137 (A) 121	NTCC138 (A) 121	NTCC139 (A) 121	NTCC140 (A) 121	NTCC141 (A) 121	NTCC142 (A) 121	NTCC143 (A) 121
NTCC144 (A) 121	NTCC145 (A) 121	NTCC146 (A) 121	NTCC147 (A) 121	NTCC148 (A) 121	NTCC149 (A) 121	NTCC150 (A) 121	NTCC151 (A) 121	NTCC152 (A) 121	NTCC153 (A) 121	NTCC154 (A) 121
NTCC155 (A) 121	NTCC156 (A) 121	NTCC157 (A) 121	NTCC158 (A) 121	NTCC159 (A) 121	NTCC160 (A) 121	NTCC161 (A) 121	NTCC162 (A) 121	NTCC163 (A) 121	NTCC164 (A) 121	NTCC165 (A) 121
NTCC166 (A) 121	NTCC167 (A) 121	NTCC168 (A) 121	NTCC169 (A) 121	NTCC170 (A) 121	NTCC171 (A) 121	NTCC172 (A) 121	NTCC173 (A) 121	NTCC174 (A) 121	NTCC175 (A) 121	NTCC176 (A) 121
NTCC177 (A) 121	NTCC178 (A) 121	NTCC179 (A) 121	NTCC180 (A) 121	NTCC181 (A) 121	NTCC182 (A) 121	NTCC183 (A) 121	NTCC184 (A) 121	NTCC185 (A) 121	NTCC186 (A) 121	NTCC187 (A) 121
NTCC188 (A) 121	NTCC189 (A) 121	NTCC190 (A) 121	NTCC191 (A) 121	NTCC192 (A) 121	NTCC193 (A) 121	NTCC194 (A) 121	NTCC195 (A) 121	NTCC196 (A) 121	NTCC197 (A) 121	NTCC198 (A) 121
NTCC199 (A) 121	NTCC200 (A) 121	NTCC201 (A) 121	NTCC202 (A) 121	NTCC203 (A) 121	NTCC204 (A) 121	NTCC205 (A) 121	NTCC206 (A) 121	NTCC207 (A) 121	NTCC208 (A) 121	NTCC209 (A) 121
NTCC210 (A) 121	NTCC211 (A) 121	NTCC212 (A) 121	NTCC213 (A) 121	NTCC214 (A) 121	NTCC215 (A) 121	NTCC216 (A) 121	NTCC217 (A) 121	NTCC218 (A) 121	NTCC219 (A) 121	NTCC220 (A) 121
NTCC221 (A) 121	NTCC222 (A) 121	NTCC223 (A) 121	NTCC224 (A) 121	NTCC225 (A) 121	NTCC226 (A) 121	NTCC227 (A) 121	NTCC228 (A) 121	NTCC229 (A) 121	NTCC230 (A) 121	NTCC231 (A) 121
NTCC232 (A) 121	NTCC233 (A) 121	NTCC234 (A) 121	NTCC235 (A) 121	NTCC236 (A) 121	NTCC237 (A) 121	NTCC238 (A) 121	NTCC239 (A) 121	NTCC240 (A) 121	NTCC241 (A) 121	NTCC242 (A) 121
NTCC243 (A) 121	NTCC244 (A) 121	NTCC245 (A) 121	NTCC246 (A) 121	NTCC247 (A) 121	NTCC248 (A) 121	NTCC249 (A) 121	NTCC250 (A) 121	NTCC251 (A) 121	NTCC252 (A) 121	NTCC253 (A) 121
NTCC254 (A) 121	NTCC255 (A) 121	NTCC256 (A) 121	NTCC257 (A) 121	NTCC258 (A) 121	NTCC259 (A) 121	NTCC260 (A) 121	NTCC261 (A) 121	NTCC262 (A) 121	NTCC263 (A) 121	NTCC264 (A) 121
NTCC265 (A) 121	NTCC266 (A) 121	NTCC267 (A) 121	NTCC268 (A) 121	NTCC269 (A) 121	NTCC270 (A) 121	NTCC271 (A) 121	NTCC272 (A) 121	NTCC273 (A) 121	NTCC274 (A) 121	NTCC275 (A) 121
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NTCC287 (A) 121	NTCC288 (A) 121	NTCC289 (A) 121	NTCC290 (A) 121	NTCC291 (A) 121	NTCC292 (A) 121	NTCC293 (A) 121	NTCC294 (A) 121	NTCC295 (A) 121	NTCC296 (A) 121	NTCC297 (A) 121
NTCC298 (A) 121	NTCC299 (A) 121	NTCC300 (A) 121	NTCC301 (A) 121	NTCC302 (A) 121	NTCC303 (A) 121	NTCC304 (A) 121	NTCC305 (A) 121	NTCC306 (A) 121	NTCC307 (A) 121	NTCC308 (A) 121
NTCC309 (A) 121	NTCC310 (A) 121	NTCC311 (A) 121	NTCC312 (A) 121	NTCC313 (A) 121	NTCC314 (A) 121	NTCC315 (A) 121	NTCC316 (A) 121	NTCC317 (A) 121	NTCC318 (A) 121	NTCC319 (A) 121
NTCC320 (A) 121	NTCC321 (A) 121	NTCC322 (A) 121	NTCC323 (A) 121	NTCC324 (A) 121	NTCC325 (A) 121	NTCC326 (A) 121	NTCC327 (A) 121	NTCC328 (A) 121	NTCC329 (A) 121	NTCC330 (A) 121
NTCC331 (A) 121	NTCC332 (A) 121	NTCC333 (A) 121	NTCC334 (A) 121	NTCC335 (A) 121	NTCC336 (A) 121	NTCC337 (A) 121	NTCC338 (A) 121	NTCC339 (A) 121	NTCC340 (A) 121	NTCC341 (A) 121
NTCC342 (A) 121	NTCC343 (A) 121	NTCC344 (A) 121	NTCC345 (A) 121	NTCC346 (A) 121	NTCC347 (A) 121	NTCC348 (A) 121	NTCC349 (A) 121	NTCC350 (A) 121	NTCC351 (A) 121	NTCC352 (A) 121
NTCC353 (A) 121	NTCC354 (A) 121	NTCC355 (A) 121	NTCC356 (A) 121	NTCC357 (A) 121	NTCC358 (A) 121	NTCC359 (A) 121	NTCC360 (A) 121	NTCC361 (A) 121	NTCC362 (A) 121	NTCC363 (A) 121
NTCC364 (A) 121	NTCC365 (A) 121	NTCC366 (A) 121	NTCC367 (A) 121	NTCC368 (A) 121	NTCC369 (A) 121	NTCC370 (A) 121	NTCC371 (A) 121	NTCC372 (A) 121	NTCC373 (A) 121	NTCC374 (A) 121
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NTCC386 (A) 121	NTCC387 (A) 121	NTCC388 (A) 121	NTCC389 (A) 121	NTCC390 (A) 121	NTCC391 (A) 121	NTCC392 (A) 121	NTCC393 (A) 121	NTCC394 (A) 121	NTCC395 (A) 121	NTCC396 (A) 121
NTCC397 (A) 121	NTCC398 (A) 121	NTCC399 (A) 121	NTCC400 (A) 121	NTCC401 (A) 121	NTCC402 (A) 121	NTCC403 (A) 121	NTCC404 (A) 121	NTCC405 (A) 121	NTCC406 (A) 121	NTCC407 (A) 121
NTCC408 (A) 121	NTCC409 (A) 121	NTCC410 (A) 121	NTCC411 (A) 121	NTCC412 (A) 121	NTCC413 (A) 121	NTCC414 (A) 121	NTCC415 (A) 121	NTCC416 (A) 121	NTCC417 (A) 121	NTCC418 (A) 121
NTCC419 (A) 121	NTCC420 (A) 121	NTCC421 (A) 121	NTCC422 (A) 121	NTCC423 (A) 121	NTCC424 (A) 121	NTCC425 (A) 121	NTCC426 (A) 121	NTCC427 (A) 121	NTCC428 (A) 121	NTCC429 (A) 121
NTCC430 (A) 121	NTCC431 (A) 121	NTCC432 (A) 121	NTCC433 (A) 121	NTCC434 (A) 121	NTCC435 (A) 121	NTCC436 (A) 121	NTCC437 (A) 121	NTCC438 (A) 121	NTCC439 (A) 121	NTCC440 (A) 121
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NTCC507 (A) 121	NTCC508 (A) 121	NTCC509 (A) 121	NTCC510 (A) 121	NTCC511 (A) 121	NTCC512 (A) 121	NTCC513 (A) 121	NTCC514 (A) 121	NTCC515 (A) 121	NTCC516 (A) 121	NTCC517 (A) 121
NTCC518 (A) 121	NTCC519 (A) 121	NTCC520 (A) 121	NTCC521 (A) 121	NTCC522 (A) 121	NTCC523 (A) 121	NTCC524 (A) 121	NTCC525 (A) 121	NTCC526 (A) 121	NTCC527 (A) 121	NTCC528 (A) 121
NTCC529 (A) 121	NTCC530 (A) 121	NTCC531 (A) 121	NTCC532 (A) 121	NTCC533 (A) 121	NTCC534 (A) 121	NTCC535 (A) 121	NTCC536 (A) 121	NTCC537 (A) 121	NTCC538 (A) 121	NTCC539 (A) 121

To test the new system's accuracy, reliability, and robustness, we carried out a set of tests. We verified the timestamps of data from all servers. The BedMaster data time is compared with the CCATT viewer displayed time. We visited dozens of bed units in the hospital to compare CCATT data with the bedside display. During the visit, we discovered a time zone shift between the mobile device and the BedMaster server. We fixed the issue, and the CCATT always shows the timestamp of the local time zone.

We also have conducted stress testing of the CCATT servers. We requested volunteer users to launch many clients and keep them running for a long time. A monitoring page was created to log all the clients' online status, from which we could know their online duration and the servers' load distribution (Figure 9).

Total 9 active clients now. Historical peak: 20 clients.			
CCATT01 serves 4 clients (44.44%), CCATT02 serves 3 clients (33.33%), CCATT03 serves 2 clients (22.22%).			
Client	IP	Server	Alive for
4th floor	10.37.72.148	CCATT-02	80d:5h
Anes WkRm	10.37.56.238	CCATT-01	60d:12h
Dr. Stein	10.37.48.216	CCATT-01	40d:9h
Unknown	10.32.62.14	CCATT-01	0 min
Unknown	10.32.60.4	CCATT-03	0 min
Unknown	10.32.60.4	CCATT-02	3 min
Unknown	10.32.60.4	CCATT-01	2 min
Unknown	10.14.1.18	CCATT-02	0 min
Unknown	10.14.1.254	CCATT-03	0 min
Inactive clients in past 24 hours		Click here to expand/collapse.	
Unknown	10.32.60.4	CCATT-02	3 min
Unknown	10.32.60.4	CCATT-03	2h:7m

Figure 9. A page to monitor clients' online status and CCATT servers' load distribution.

4.0 VALIDATION IN A REAL TRAUMA CENTER

In the R Adams Cowley STC, a level 1 regional trauma center located in downtown Baltimore, Maryland, 94 GE-Marquette-Solar-7000/8000® (General Electric, Fairfield, CT) patient VS monitors are networked to provide collection of real-time patient VS data streams in 13 TRU, 9 operating room OR, 12 post-anesthesia care, and 60 ICU individual bed/monitor units. Each patient monitor collects real-time 240-Hz waveforms and 0.5-Hz trends data, which are transferred via secure intranet to a dedicated BedMaster® server (Excel Medical Electronics, Jupiter, FL) and archived [8]. This process generates approximately 20 million data points/day/bed or roughly 30 terabits/year of data. Physiological data collected through this system, when they are displayed on the GE Marquette monitor, include electrocardiographic, photoplethysmographic, carbon dioxide, arterial blood pressure, and ICP, among others. Trends include HR, RR, temperature, SpO2, EtCO2, and ICP, among many others. They cover the categories of brain pressure, cardiac, perfusion, and respiratory.

STC attendings, physician assistants, nurse practitioners, and fellows were trained and familiarized with the viewer in sessions. After training, the clinicians filled out a survey soliciting feedback on the ICU viewer. Research staff shadowed STC attendings on rounds to

gain experience to develop the viewer validation questionnaire. On rounds, the research staff documented the following:

1. All clinical judgments, orders, and treatment decisions made by clinicians as an open-ended survey – document which unit you are in, which types of rounds, and the judgments & decisions made.
2. When shadowing through the rounds, study the logistics, the different units, different types of rounds, and think about it from the point of view of when having a research coordinator give a clinician or nurse a survey would be least disruptive and most welcome.

Based on these data and several dedicated survey design meetings, with participation by senior trauma physicians, USAF physicians, study coordinators, principal investigators, and system design team members, a survey was generated and adjusted. The survey was used on rounds on multiple occasions before the survey was uploaded to an online database. During rounds, the survey link was pulled up for the attending on one of two tablets purchased for that purpose. On the rare occasion that the server failed, paper surveys were available and used to collect data.

Physicians who were scheduled to work in the ICU or on the team were contacted and trained on how to use the CCATT viewer. Once trained, ICU and team attendings were asked to participate in the study. Those willing were surveyed during morning rounds on ICU patients; those unwilling were rarely asked again. Physicians were only surveyed Tuesday-Friday and were asked to conduct rounds normally, using data reported from nurse charts and briefs from fellows to inform their clinical decisions. After the physicians finished their assessment and plan for the patient, they were given the pre-view questionnaire to fill out (Appendix A). Immediately after that, the CCATT viewer was presented to the physicians on a tablet PC displaying the patient's past physiologic data visualized and summarized up to 72 hours. After looking at the CCATT viewer for as long as they would like, typically for 1 minute or less, the physicians filled out the post-view questionnaire (Appendix B). In both questionnaires, the physicians are asked questions regarding the patient's stability, status, and need for a higher or lower level of care. Physicians were also asked if they intentionally plan on any of the following interventions after seeing the viewer: (a) changing any current medications, (b) ordering additional medications, (c) ordering additional diagnostic tests, (d) changing ventilation settings, (e) ordering additional labs, (f) physically reexamining this patient, (g) providing fluid bolus, or (h) providing a blood transfusion.

5.0 RESULTS

5.1 Overall Results

From February 15, 2017, to June 30, 2017, 908 surveys were collected. Besides the questions from the survey forms, we also collected the survey time, rounding type (trauma team or ICU), and whether the patient was admitted to the ICU in the last 24 hours (Figure 10). There were 758 (83%) surveys collected from the ICU and 150 (17%) from the team. Among the 908 rounds, 48 (5%) were new STC admission in the last 24 hours and 860 (95%) were not. We compared the clinicians' evaluations on the patients before and after seeing the CCATT viewer.

Figures 11-14 show that the CCATT viewer could support their initial evaluations on infection, hemodynamic status, general condition, etc. Specifically, we asked the clinicians the following:

1. Having reviewed the last 24 hours information during rounds and before/after seeing the 24-hour CCATT viewer, do they feel that in the past 24 hours the patient has shown evidence of (a) infection, (b) hemodynamic instability, (c) uncontrolled bleeding, or (d) respiratory deterioration?
2. Over the past 24 hours, the patient's condition has (a) improved significantly, (b) improved slightly, (c) unchanged, (d) deteriorated slightly, or (e) deteriorated significantly.
3. Can the patient be transferred to a lower level of care?
4. Can the patient be transferred to a higher level of care?
5. Does the patient have TBI?
6. Did the patient have ICP problems in the past 24 hours?
7. Due to the viewer, do they plan for any changes of interventions, including (a) changing any current medications, (b) ordering additional medications, (c) ordering additional diagnostic tests, (d) changing ventilation settings, (e) ordering additional labs, (f) physically reexamining this patient, (g) providing a fluid bolus, or (h) providing a blood transfusion?
8. Does the viewer enhance their understanding of the patient's condition?

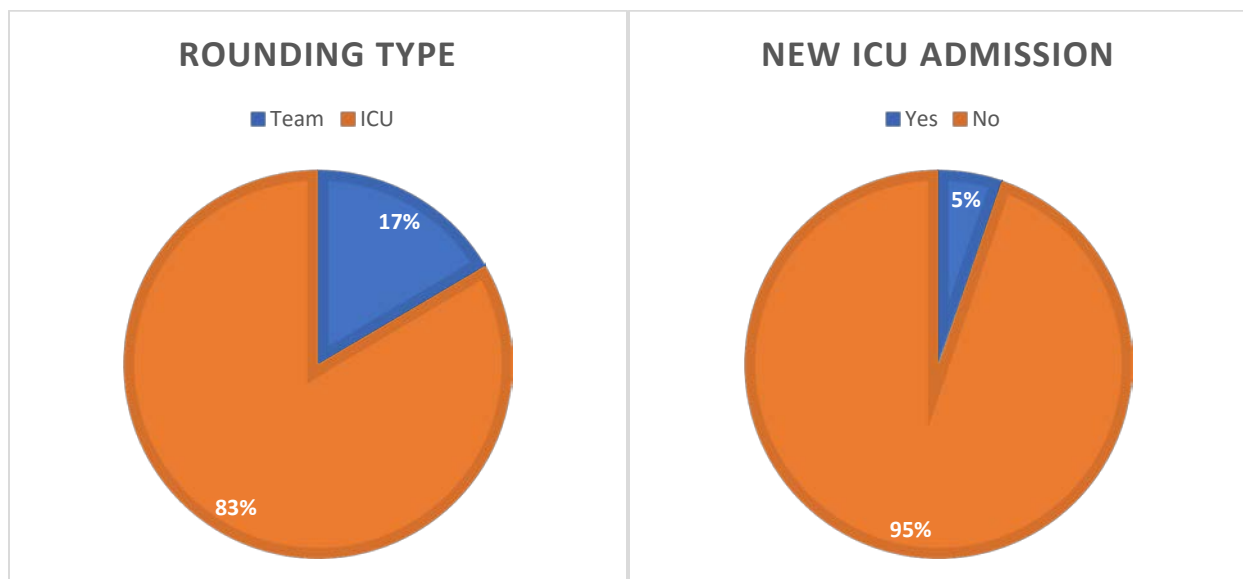


Figure 10. Pie charts of rounding type and percentage of patients who were new STC admissions in last 24 h.

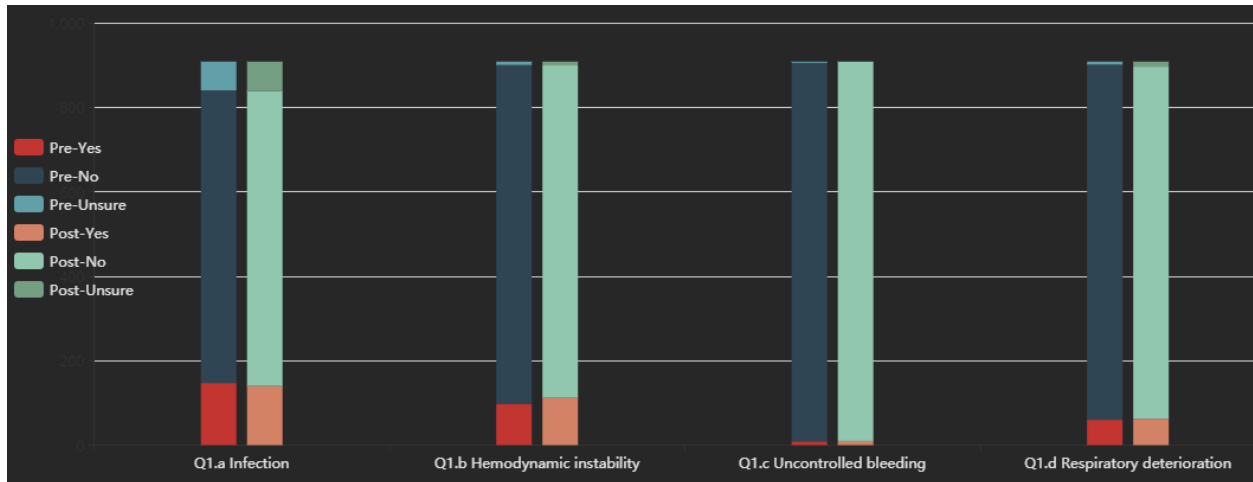


Figure 11. Comparison of answers on the following question: “Having reviewed the last 24 h during rounds [left bar]/CCATT viewer [right bar], I feel that in the past 24 h this patient has shown evidence of (a) infection, (b) hemodynamic instability, (c) uncontrolled bleeding, or (d) respiratory deterioration.”

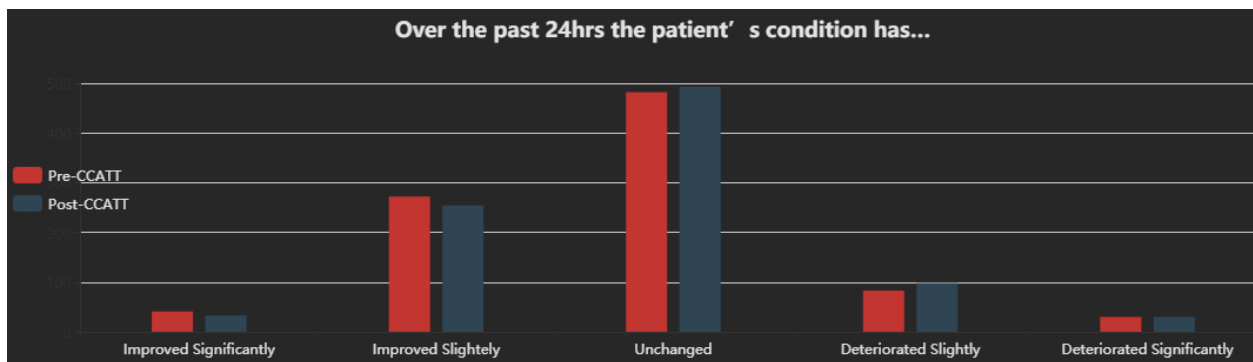


Figure 12. Comparison of answers before and after viewing the CCATT viewer for the following question: “Over the past 24 h the patient’s condition has (1) improved significantly, (2) improved slightly, (3) unchanged, (4) deteriorated slightly, or (5) deteriorated significantly.”

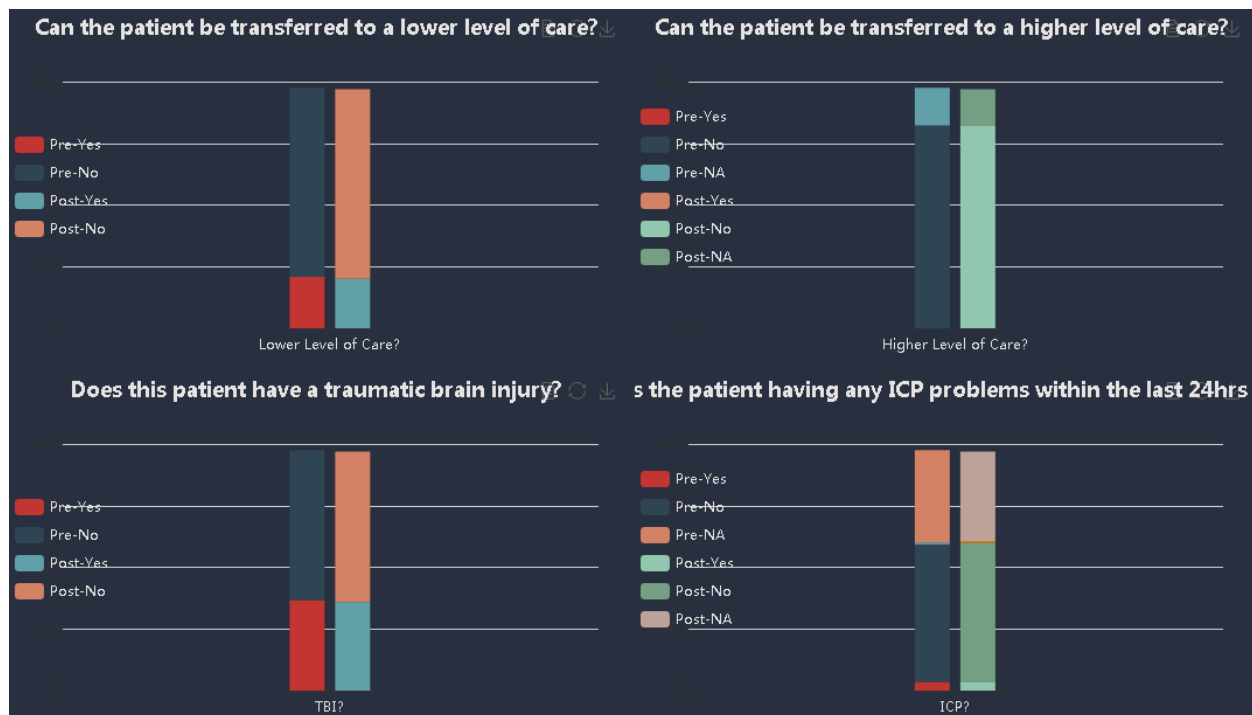


Figure 13. Comparison of answers before and after seeing the CCATT viewer for the following questions: (1) Can the patient be transferred to a lower level of care? (2) Does the patient need to be transferred to a higher level of care? (3) Does this patient have a traumatic brain injury? (4) Is the patient having any ICP problems within the last 24 h?

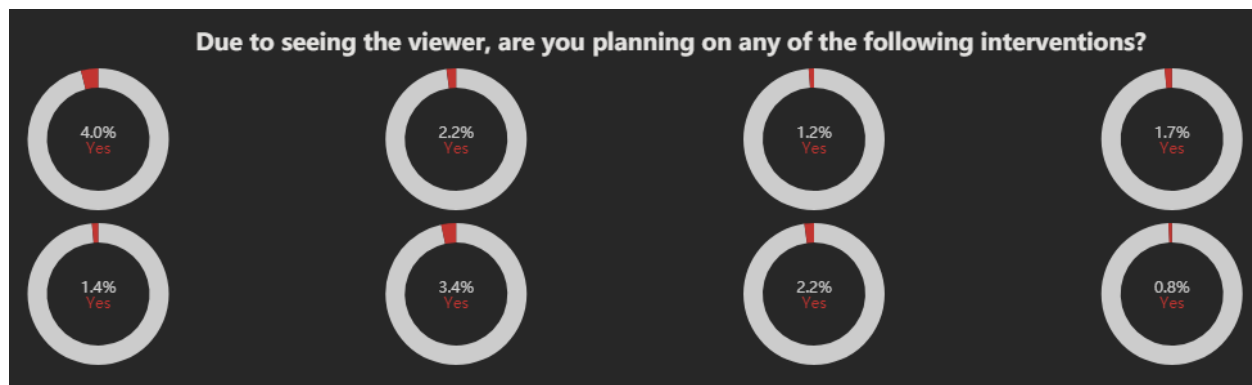


Figure 14. Ring charts for percentage of surveyed attendings positively planning interventions due to seeing the CCATT viewer.

Overall, during the 908 surveys when asked if the CCATT viewer enhanced their understanding of the patient's condition, physicians strongly agreed 45 times (4.96%), agreed 514 times (56.61%), were neutral 321 times (35.35%), disagreed 26 times (2.86%), and strongly disagreed 2 times (0.22%) (Figure 15).

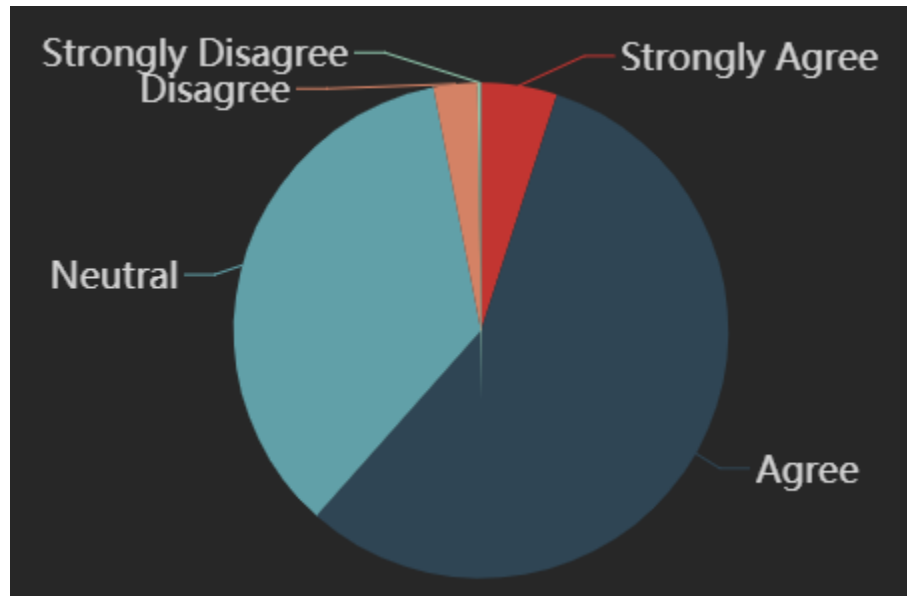


Figure 15. Pie chart showing clinicians' rating of the CCATT viewer.

Results show that physicians' clinical assessments and plans could be influenced by viewing the CCATT viewer for 1 minute or less, indicated by a "yes" answer to at least one of the eight questions. The most common change was (a) change current medications (4.0%). The next most common changes were (f) physically reexamining the patient (3.4%), (b) ordering additional medications (2.2%), and (g) providing a fluid bolus (2.2%). Other responses are shown in Figure 14.

5.2 Types of Participants

To collect and keep as many data as possible, the survey team followed clinicians who agreed to take the surveys. Twenty-four unique participants finished 908 surveys with unbalanced proportions. Figure 16 summarizes the total number of surveys that each participant had completed. The top one contributed 154 (16%) surveys, followed by 118 (13%) and 113 (12.4%) from two other participants. One participant contributed only one survey and strongly disagreed that the CCATT viewer enhanced his/her understanding of the patient's condition. The distribution of the number of surveys taken and the rating on the viewer indicate the participants may have different *a priori* attitude toward the use of the viewer. Clinicians may have different receptiveness to the new tool and various way to manage information during rounding. Therefore, their perception of usefulness of the viewer is different. The subjective question "the viewer enhanced my understanding of the patient's condition" can be used to separate the participants into different types.

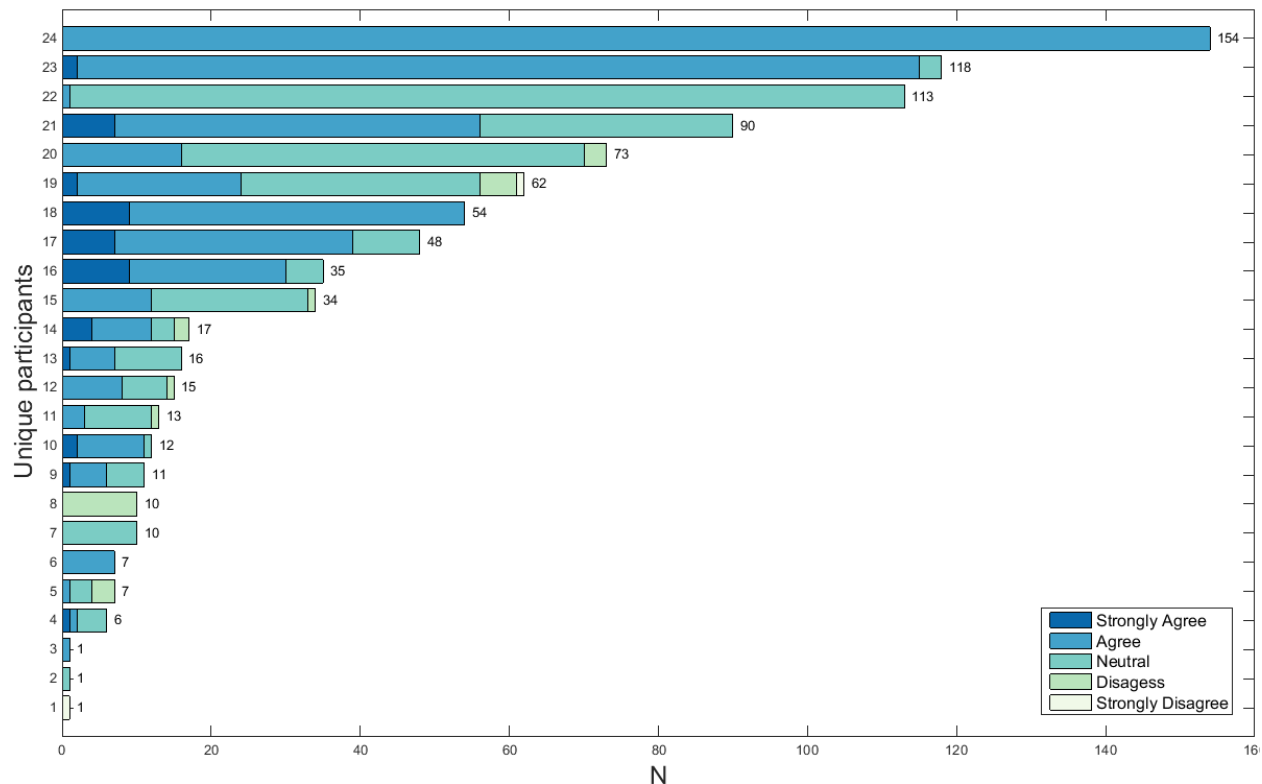


Figure 16. Distribution of each participant’s rating on if the viewer enhanced his/her understanding of the patient’s condition during a round.

We used a clustering method to group the participants based on their ratings for each rounding. A participant is represented by a vector, consisting of the percentage of the five categories that he/she assigned to the question “the viewer enhanced my understanding of the patient’s condition.” For example, one participant contributed 62 surveys and rated 2 “strongly agree,” 22 “agree,” 32 “neutral,” 5 “disagree,” and 1 “strongly disagree.” The percentages of the rates 0.03, 0.35, 0.52, 0.08, and 0.02 together represent the overall attitude that this participant had about the viewer. Based on Manhattan distance, the 24 participants were clustered into five groups, as shown in Figure 17. The five groups correspond to the participants who are from mostly in favor (C1) of the viewer to those least in favor (C5). There are six in C1, six in C2, three in C3, seven in C4, and two in C5, which shows a very balanced grouping, with half of the participants in the C1 and C2 groups and the other half in the other three clusters. This shows that the sampled rounds were done by participants with almost similar proportions of different attitudes toward the viewer. In other words, the survey team sampled the rounds random enough such that the collected data are not biased by participants with certain preexisting feelings about the viewer.

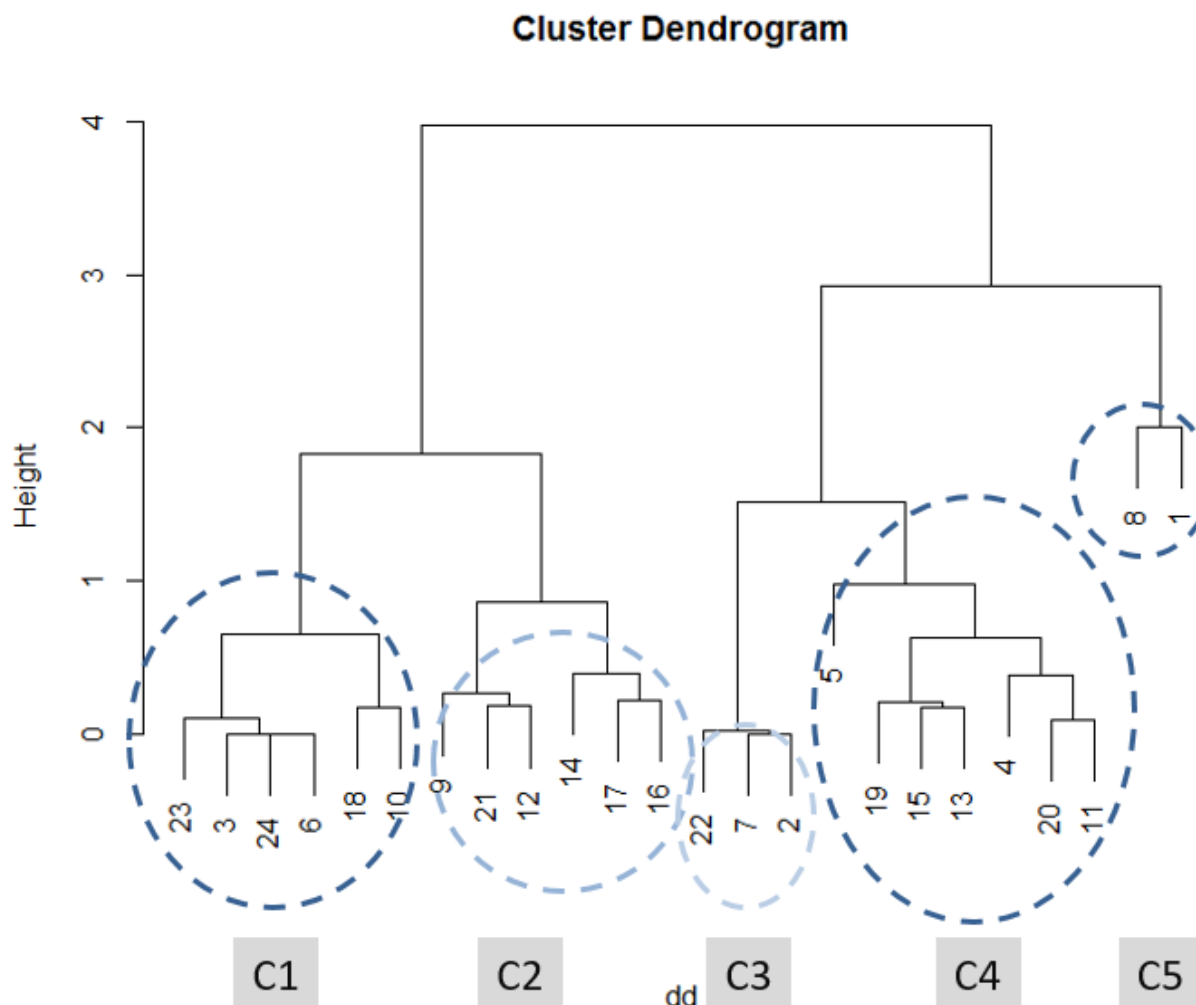


Figure 17. Clusters of participants with similar feelings about the viewer. In total, 24 unique participants are grouped into five groups, corresponding to “strongly favor,” “favor,” “neutral,” “dislike,” and “strongly dislike.”

5.3 Comparison using the Clusters

For questions 1-7 listed in section 5.1, we analyzed the changes between before and after seeing the viewer, with respect to the clusters of user types. In question 1, the physicians were asked, “*Having reviewed the last 24 hours information during rounds and before / after seeing the 24-hour CCATT viewer, do they feel that in the past 24 hours the patient has shown evidence of (a) infection, (b) hemodynamic instability, (c) uncontrolled bleeding, or (d) respiratory deterioration?*” For all the four events, physicians’ answers could be “yes,” “no,” or “unsure.” There were changes from before and after seeing the viewer 129 times (14.21%). Sixteen participants (66.7%) had used the viewer’s information to make changes. In terms of the clusters of user types, there were 46, 31, 10, 42, and 0 times of any opinion changes occurring in user clusters C1 to C5.

In question 2, physicians were asked, “*Over the past 24 hours, the patient’s condition has (a) improved significantly, (b) improved slightly, (c) unchanged, (d) deteriorated slightly, or (e) deteriorated significantly.*” Their answer could be any one of above five opinions. There were

112 times (12.33%) of changes from before and after seeing the viewer. Fifteen participants (62.5%) had used the viewer's information to make changes. Among the five clusters, there were 38, 34, 8, 32, and 0 times any changes occurred.

Questions 3-6 can be considered as a group of similar questions. The answers could be "yes," "no," or "not applicable." There were 145 times (15.97%) of changes from before and after seeing the viewer. Eighteen participants (75%) had used the viewer's information to make changes. There were 58, 54, 3, 30, and 0 times changes occurred in each of the five clusters.

For question 7, physicians were asked, "*Due to the viewer, do you plan for any changes of interventions, including (a) changing any current medications, (b) ordering additional medications, (c) ordering additional diagnostic tests, (d) changing ventilation settings, (e) ordering additional labs, (f) physically reexamining this patient, (g) providing a fluid bolus, or (h) providing a blood transfusion.*" Their answer could be "yes" or "no" to any combination of above eight options. A total 92 times (10.13%) rounds had at least one "yes" answer as planning on some of the interventions. Seventeen participants (70.83%) had used the viewer's information and planned some of the interventions. In the five clusters, there were 20, 32, 9, 31, and 0 times of planning. Table 3 shows the numbers of rounds in which physicians had from 0 to 8 planned interventions due to seeing the viewer.

Table 3. Numbers of Rounds in which Physicians Had from 0 to 8 Planned Interventions Due to Seeing the Viewer

No. of Planned Interventions	No. of Rounds	Percentage in All Rounds
0	816	98.87
1	61	6.72
2	13	1.42
3	12	1.32
4	3	0.33
5	1	0.11
6	1	0.11
7	1	0.11
8	0	0.00

5.4 Other Factors

The 908 surveys were collected from weekdays (except Mondays) in 4.5 months. The survey team followed the rounds and asked the leading physicians who were randomly selected and willing to take the survey. In this section, we visualize the daily collected data and see from the dimensions of time and round type.

First, we visualized the distribution of daily collected surveys along the 4.5 months (Figure 18). The 908 surveys were collected over 71 days, 13 surveys per day on average. The median collection rate was 12 surveys per day. The minimum collection rate was 1 survey in a day, and it peaked at 27 surveys in a day. There was no obvious type of distribution of the daily collection rate, either normal or uniform distribution. It shows some randomness. However, it is true that the overall daily collection rate was lower at the end than in the beginning. This is

because of the fatigue brought on by the repeated survey. But in general, there is no evidence that the surveys were collected from a particular period of time.

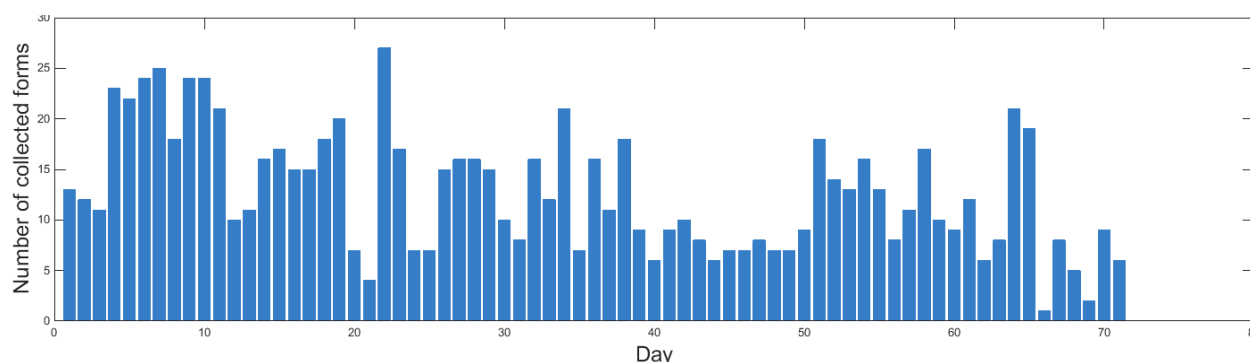


Figure 18. Number of surveys collected on each day during this study.

There are two types of rounds: team and ICU. There are three patient receiving teams led by a trauma surgeon at our trauma center. A trauma patient admitted to our trauma center is met by one of the team members. The team is responsible for following the patient throughout the trauma center stay. Team rounds are more focused on the patient's care plan such as when to go to the OR or if the patient can be moved to a lower level of care, etc. ICU rounds are led by the ICU intensivists (clinicians with critical care certification). They will round through all the patients in the unit. They are more focused on the patient's stability in the unit and coordinate care with each of the specialists (orthopedic, cardiovascular, pulmonary, infectious diseases) as needed. There were more surveys collected from ICU rounds, but the two types were spread out over the collection time (Figure 19). Table 4 summarizes the number of surveys with answer changes in terms of round type. For questions 1 and 3-6, there was no significantly different proportion of changes between the team and ICU rounds. For questions 2 and 7, team rounds had a higher answer change percentage than ICU rounds.

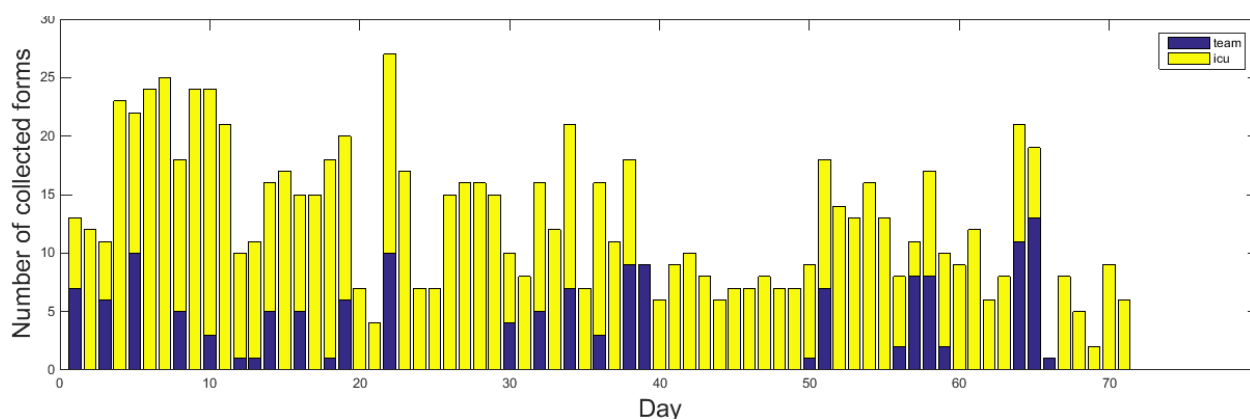


Figure 19. Number of surveys collected from team (blue) or ICU (yellow) rounds during each day of this study.

Table 4. Number of Surveys with Answer Changes Before and After Seeing the Viewer in Terms of Round Type

Question	Team (N=150)	ICU (N=758)	Proportional Test p-Value
1	24 (16.00%)	105 (13.85%)	0.575
2	28 (18.67%)	84 (11.08%)	0.015
3-6	25 (16.67%)	120 (15.83%)	0.894
7	26 (17.33%)	66 (8.71%)	0.001

6.0 DISCUSSION

6.1 Usefulness

CCATT was created for fast, reliable AE. In the Vietnam War, it took about 45 days to transport patients from the front line to home, 10 days during Desert Shield/Storm, and less than 3 days in today's war zones. Initiated in 1994, the USAF CCATT has transported more than 8000 patients, among which up to 80% were trauma patients [9]. The team consists of a compact and specialized medical crew. They provide necessary medical care to a group of patients onboard during flight. The airplane serves as a portable ICU, but with very limited resources. CCATT has been proved to be useful in transporting critically injured patients with short-term complications [10,11]. However, these compact medical teams constantly face challenges regarding in-flight assessments that are required to rapidly render appropriate clinical support. Clinical decision-making is further confounded by an aeromedical environment characterized by confined space, noise, vibration, and limited visibility.

The viewer, which automates physiological data-organizing and information-summary, could present aggregated information from multiple data sources, provide at-a-glance summaries of clinical data, and assist with prioritizing care for multiple patients. The platform presents trends in patients' condition with simple color codes, which can greatly improve situational awareness. In addition to a small group of patients, the viewer is scalable to large hospitals with hundreds of beds.

6.2 Evaluation

The CCATT viewer has been deployed and evaluated in a regional level 1 trauma center. The trauma center environment shares some similarity with the military airplanes that fly the CCATTs. They both have busy and confined spaces, which are surrounded by many medical devices. The military airplanes are enormously noisy during flight, which makes most medical acoustic alarms hard to hear. In civilian hospitals, alarm fatigue also exists due to continuous alarms. Both currently use bedside monitors that display individual patients' instantaneous VS readings without easy access to a trajectory view. Therefore, a new VS monitoring tool, such as the CCATT viewer, could be used to improve situational awareness in both military and civilian hospital environments.

Morning rounds in a civilian trauma center ICU are conducted in a busy environment with many data sources, which is similar to a busy and confined transport aircraft. Physicians in both environments must make high-stakes decisions using loosely organized physiological data and are often oversaturated with information of varying quality. The survey shows that organized

physiologic data and visual assessment could possibly assist clinicians to recognize changes in patient status and prioritize care.

Moreover, the STC generates more data streams than a CCATT airplane. Hence, the evaluation environment could serve as a stricter testing space for stress testing the viewer's capacity of processing and organizing massive amounts of data. The STC has more than 160 beds, each collecting 9 or more high-fidelity VS trajectories. On average, 9 million data points per minute are streamed and processed by the viewer. In the military CCATT airplane, typically dozens of patients or less are transported and monitored. Therefore, the data amount tested is far beyond the possible real use in the CCATT airplane.

From 908 survey forms collected from ICU attendings, we can observe that clinicians can use the viewer to recognize changes in patient status or confirm their judgment. They may discover more information within about 1 minute of looking at the viewer.

6.3 Limitations

We collected data from a large number of ICU doctors compared to team doctors. This is primarily because of the number of ICU patients ICU doctors are responsible for compared to team doctors. At the STC, team doctors are surgeons, responsible for the same patient throughout his/her stay, regardless of the acuity of the patient. ICU doctors are intensivists and are only responsible for ICU patients on their floor. Not only does this mean ICU doctors have more ICU patients, but it also means it was easier to find and talk to them in person. Team doctors had to return our pages for us to know where they were.

Some physicians were more amenable to being surveyed than others, which made it difficult to truly randomize the physicians we sampled. In the collected forms, there were more surveys from some clinicians than from others. To reduce the bias, we clustered the participants based on their overall rating on each round, from which we estimated each participant's *a priori* attitude toward using this viewer. The results show that there was balanced "favoring" and "non-favoring" of using this viewer.

Although the civilian ICU is similar to the CCATT environment, it is still different from the real AE condition. In this evaluation, we cannot simulate the vibrating, highly stressful, unstable environment. The locations, viewing point of the bedside monitors, and the viewer could be quite different from those in the airplane. The patient care protocols could be very different in a civilian ICU and the CCATT team. Therefore, it is necessary to design a new evaluation of the viewer in a real CCATT aircraft environment to determine its stability and usefulness to the crew.

6.4 Product and Impact

The VS viewer was created to run on PCs. An Android app also has been made to run the viewer's client on Android phones. The viewer system, including its architecture and visualization scheme, has been submitted for a U.S. provisional patent application under the title "Method and Apparatus for Monitoring Collection of Physiological Patient Data."

The Technology Readiness Assessment report for the CCATT viewer was submitted to the Air Force Medical Support Agency and the viewer has achieved technology readiness level 3 and emergent 4.

The CCATT viewer has been presented to a wide audience at various Department of Defense and international conferences and meetings.

7.0 CONCLUSIONS

With the development of sensing and computing technologies, vast amounts of high-quality, continuous, electronic data, including VS, alarms, and clinical interventions, are collected at the bedside. Those data have the potential to provide an unprecedented view of dynamic physiologic response to injury, illness, and treatments. Therefore, data gathered from bed-sides could assist clinicians for care planning and decision-support.

However, massive data that aren't well organized or presented still create a barrier for clinicians making full use of them in a busy resuscitation or intensive care environment. Bedside monitors often only display instantaneous readings or a short strip of recent physiologic VS for diagnosis. Clinicians need to rely on separate nursing charts, hand-written or electric, to review a patient's developing conditions. Also, auditory alarms often cause "alarm fatigue" instead of increasing situational awareness. Moreover, many bedside monitors only display one or two patients' information. Health providers lack a convenient tool to maintain an overall summary of multiple patients in different beds and hence may spend more time to track multiple patients and to decide care priority.

We designed, implemented, and evaluated an automated physiologic data organizer and visualization platform, the CCATT viewer. It provides at-a-glance summaries and assists with prioritizing care for multiple patients. The CCATT viewer prototype demonstrates a method to assemble large quantities of data from multiple sources and represents trends in each patient's condition with simple color codes, greatly improving situational awareness.

Morning rounds in a civilian trauma center ICU are conducted in a busy environment with many data sources, which is similar to a busy and confined transport aircraft. Physicians in both environments must make high-stakes decisions using loosely organized physiological data and are often oversaturated with information of varying quality. The survey shows that the organized physiologic data and visual assessment could assist clinicians to recognize changes in patient status and prioritize care.

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APPENDIX A

Survey 1, Pre-CCATT Viewer Questionnaire

**CCATT Viewer
Rounding Survey**

Badge ID#: _ _ _ _
Rounding Type: Team/ICU
Floor: 4IMC/4ICU/5IMC/5ICU/6IMC
New STC Admit in last 24 h: Yes/No

After traditional rounds and before accessing the viewer

Directions: For the following questions please circle your responses

1. I have previewed the viewer for this patient before rounding. *Yes* *No*

2. Having reviewed the last 24 h during rounds, I feel that in the past 24 h this patient has shown evidence of:

a. Infection	<i>Yes</i>	<i>No</i>	<i>Unsure</i>
b. Hemodynamic instability	<i>Yes</i>	<i>No</i>	<i>Unsure</i>
c. Uncontrolled bleeding	<i>Yes</i>	<i>No</i>	<i>Unsure</i>
d. Respiratory deterioration	<i>Yes</i>	<i>No</i>	<i>Unsure</i>

3. Over the past 24 h the patient's condition has

<i>Improved significantly</i>	<i>Improved slightly</i>	<i>Unchanged</i>	<i>Deteriorated slightly</i>	<i>Deteriorated significantly</i>
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>

4. Can the patient be transferred to a lower level of care? *Yes* *No*

5. Does the patient need to be transferred to a higher level of care? *Yes* *No*

6. Does this patient have a traumatic brain injury? *Yes* *No*

7. Has the patient had any ICP problems within the last 24 h? *Yes* *No* *Unsure* *N/A*

*****Show Attending the Viewer*****

APPENDIX B

Survey 2, Post-CCATT Viewer Questionnaire

1. Having reviewed the last 24 h during rounds and seen the 24-h CCATT viewer screen, I feel that in the past 24 h this patient has shown evidence of:

a. Infection	<i>Yes</i>	<i>No</i>	<i>Unsure</i>
b. Hemodynamic instability	<i>Yes</i>	<i>No</i>	<i>Unsure</i>
c. Uncontrolled bleeding	<i>Yes</i>	<i>No</i>	<i>Unsure</i>
d. Respiratory deterioration	<i>Yes</i>	<i>No</i>	<i>Unsure</i>

2. Over the past 24 h the patient's condition has

<i>Improved significantly</i>	<i>Improved slightly</i>	<i>Unchanged</i>	<i>Deteriorated slightly</i>	<i>Deteriorated significantly</i>
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>

3. Can the patient be transferred to a lower level of care? *Yes* *No*
4. Does the patient need to be transferred to a higher level of care? *Yes* *No*
5. Does this patient have a traumatic brain injury? *Yes* *No*
6. Has the patient had any ICP problems within the last 24 h? *Yes* *No* *Unsure* *N/A*
7. Due to seeing the viewer, are you planning on any of the following interventions?
- | | | |
|---|------------|-----------|
| a. Changing any current medications | <i>Yes</i> | <i>No</i> |
| b. Ordering additional medications | <i>Yes</i> | <i>No</i> |
| c. Ordering additional diagnostic tests | <i>Yes</i> | <i>No</i> |
| d. Changing ventilation settings | <i>Yes</i> | <i>No</i> |
| e. Ordering additional labs | <i>Yes</i> | <i>No</i> |
| f. Physically reexamining this patient | <i>Yes</i> | <i>No</i> |
| g. Providing a fluid bolus | <i>Yes</i> | <i>No</i> |
| h. Providing a blood transfusion | <i>Yes</i> | <i>No</i> |

8. I found that the CCATT viewer enhanced my understanding of the patient's condition.

<i>Strongly Agree</i>	<i>Agree</i>	<i>Neutral</i>	<i>Disagree</i>	<i>Strongly Disagree</i>
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>

LIST OF ABBREVIATIONS AND ACRONYMS

2D	two-dimensional
AE	aeromedical evacuation
BTI	brain trauma index
CCATT	Critical Care Air Transport Team
CPP	cerebral perfusion pressure
DBP	diastolic blood pressure
EtCO₂	end-tidal carbon dioxide
HR	heart rate
ICP	intracranial pressure
ICU	intensive care unit
MoMs	monitor of monitors
OR	operating room
PC	personal computer
RR	respiratory rate
SBP	systolic blood pressure
SI	shock index
SpO₂	blood oxygen saturation (pulse oximetry)
STC	Shock Trauma Center
TRU	trauma resuscitation unit
USAF	U.S. Air Force
VS	vital signs